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IFRO Report



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IFRO Report 287

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1. Introduction

The environmental impacts of fisheries and aquaculture most often get an entirely negative presentation in the media because of emissions of nutrients and other pollutants as well as their perceived negative influence on fish stocks and the sea bed. This negative image is also reflected in the way that the two sectors are regulated, including restrictions on catches, closed areas for fisheries and practically a moratorium for new aquaculture production sites in the Baltic Sea. However, in some cases, there is an inconsistency between the actual environmental effects and the way that the sectors are regulated. In cases where the production has a positive externality that are not taken into account by regulators, the sectors might be over-regulated and are restricted to produce less than what is optimal for the society as a whole. If an environmental resource should be utilised in the most optimal way for society, it is necessary to take into account all aspects of the activity, the positive as well as the negative.

In recent years there has been an increased focus on a more integrated maritime strategy and governance, and it is therefore important to identify the interactions between sectors that affect the marine environment. The discharge of nutrients to the marine environment from land or sea based industries creates problems, such as eutrophication and hypoxia in the estuarine and marine environment. On the other hand, fish stocks and life in the oceans in general rely on a certain level of nutrients in the water to create the foundation for the marine food-web such as plankton. When the fish is growing it feeds on organisms that have been using nutrients from the sea to grow, and when the fish is harvested the nutrients such as nitrogen and phosphorus are removed. It is therefore important to investigate these interactions and how individual sectors contribute to this balance. The Baltic Sea fisheries contribute positively to this balance.

To be able to make a coherent marine strategy that does not overlook important contributions and can create a more balanced view of the possibilities for blue growth, it is important to evaluate the positive externalities contributed by fisheries and how the negative externalities originated from fish production in aquaculture can be handled. In the case where Baltic fish stocks are used as feed in aquaculture production (i.e. Baltic Sea Fish Feed), it is important to evaluate both positive and negative environmental effects of these two sectors and their joint contribution to the economy. The use of Baltic Sea Fish Feed opens an option to close the nutrient loop in the aquaculture industry. If the amount of nutrients from the fish caught in the Baltic Sea corresponds to the nutrient emission from aquaculture, the isolated effect would be neutral. Furthermore, if the focus on neutralising the negative environmental effects from aquaculture creates new demand for Baltic caught fish, resulting in better exploitation of the existing fish quotas, it would lead to an increase in the value added by the fishing and aquaculture sector.

Blue growth in the Nordic fisheries and aquaculture can be achieved through the involvement of economic considerations as a factor in ecosystem management. Moreover, this requires that the economic evaluation take into account the objectives of good marine environmental status, as it is formulated based on the EU Water Framework (WFD) and Marine Strategy Framework (MSFD) Directives.

2. The aim of the study

This project will analyse two cases of the economic importance of environmental externalities:

The *first case* will focus on nitrogen and phosphorus removal as a positive externality from fisheries. This means that the removal of nutrients is considered a valuable service provided by the fishing sector. The aim is to identify the gains and analyse how these can be improved by public policies. Thus, the following two topics are analysed:

- How is the harvest of species and the structure of the fishing fleets in the Baltic Sea influenced when the positive externalities of removing nitrogen and phosphorus is taken into account?
- What is the value of the positive externality, and how can this knowledge be used to improve fisheries management as a way of handling of nitrogen and phosphorus in the Baltic Sea in the future?

The *second case* will focus on the joint environmental effect of aquaculture fish production in the Baltic Sea, taking into account the effect of using fish feed, based on Baltic caught fish. Furthermore, removal of nutrients will also be considered through Integrated Multi-Trophic Aquaculture (IMTA), production systems breeding mussels or growing seaweed to reduce local impact.

The aim of the second case study is to study the joint environmental effect from fisheries and aquaculture and identify the spill-over effects from fisheries to aquaculture using fish feed caught in the Baltic Sea (Baltic Sea feed) and how local effects can be remedied by using compensation methods (IMTA systems). If there is room to increase fishing in the Baltic Sea, and fish farmers start using Baltic Sea feed, the nutrients are re-cycled instead of added into the Baltic Sea. The possibility of production growth could create an economic incentive for fish farmers to switch to Baltic Sea feed and fishermen will increase their income and create blue growth. In this case study, the potential benefits of the use of Baltic Sea feed and compensation methods are evaluated and simulated:

- What is the joint environmental effect on nitrogen and phosphorus levels in the Baltic Sea if fish from the Baltic Sea is used as feed for the aquaculture sea cage farming industry?
- What are the potential benefits of using Baltic Sea feed?
- What are the costs and benefits of implementing local IMTA systems for recovering of nutrients to enable sustainable blue production growth in the marine aquaculture industry in the Baltic Sea?

The main focus of this study will be to uncover the positive effect of removing nitrogen and phosphorus through harvesting of fish in fisheries and aquaculture, to determine the value of these positive externalities and to evaluate sea based mitigating measures related to aquaculture production.

3. Case studies

3.1 Case study 1: The positive externality of fisheries

How is the harvest of species and the structure of the fishing fleets in the Baltic Sea influenced when the positive externalities of removing nitrogen and phosphorus is taken into account?

What is the value of the positive externality, and how can this knowledge be used to improve fisheries management as a way of handling nitrogen and phosphorus in the Baltic Sea in the future?

In order to analyse the topics specified above we model pelagic fisheries in the Baltic Sea by Danish, Swedish and Finnish vessels. These vessels primarily target herring and sprat. The pelagic fishery is used for the case study, since this is the fishery with the largest caught biomass and thus largest removal of nutrients. In total, the EU's TAC for herring and sprat was over 621.000 tonnes in 2017. The Danish, Swedish and Finnish fisheries cover around 47 per cent of these catches. In comparison to the pelagic fisheries, cod is the third most commercially important species with a total EU TAC of approximately 35.000 tonnes in 2017. The effect on nutrient reduction from this fishery is thus expected to be low compared to the pelagic fishery.

3.1.1 Methods

The interactions between nutrients, fish stocks and fishing fleets will be analysed including biologic as well as economic theory. The identified system of interactions between fleets and fish stocks will be implemented in a bio-economic model setup, covering pelagic fisheries in the Baltic Sea as discussed above. The setup makes it possible to investigate how the fishery will evolve with different fisheries management; current management plans and quota distributions, if Maximum Economic Yield (MEY) is implemented, or if Maximum Sustainable Yield (MSY) is implemented – all taking into account the economic value of nutrient reductions.

To empirically estimate the economic effects, a dynamic bio-economic model, FISHRENT (Frost et al. 2013; Salz et al. 2011), is used. The FISHRENT model is developed for analysing fisheries policies within the EU and has been used in several policy evaluations. In the model, the size and value of the positive externality (defined as the abatement cost of nitrogen and phosphorus in other sectors) is derived from different policy scenarios modelled over the next 24 years. The private profitability of the fishing sector is identified using the net present value from fishing (NPV). The socioeconomic value is calculated as the sum of private profits and the economic value of nutrient reductions.

Scenarios

In order to analyse the impact on nutrient reductions from different policies a number of scenarios based on both fisheries management and environmental regulations are defined. The scenarios are based on three dimensions: *Fisheries Regulation*, *Economic Compensation* for nutrient reduction, and *Environmental Regulation* for maximising nutrient reduction through fisheries. Below, the scenarios are presented in detail.

Fisheries regulation (FR)

The scenarios in the Fisheries Regulation (FR) dimension only analyse fisheries regulatory instruments (i.e. no direct environmental policies are modelled). Focus is on Individual Transferable Quotas (ITQ). ITQs are expected to have an indirect effect on the reduction of nitrogen and phosphorous because catch levels are affected (see e.g. Waldo et al. 2016).

In the model, three scenarios with increasing flexibility in the quota trade are defined:

1. Business as usual (FR1_BAU) where current regulatory systems are maintained
2. A national ITQ scenario (FR2_National ITQ) assuming free quota trading in a National ITQ system
3. A Baltic ITQ scenario (FR3_Baltic ITQ) assuming free quota trading within the Baltic region.

Notably, both Denmark and Sweden had ITQ systems in the studied period and thus the FR1_BAU scenario should be considered a projection of these systems into the future. The National ITQ scenario is in these cases a further rationalisation due to e.g. removing restrictions on quota trade and new investment in more efficient vessels.

Economic compensation (EC)

The scenarios concerning Economic Compensation (EC) are based on fisheries being compensated for reducing nitrogen and phosphorous. The value (and thereby compensation) is estimated to 0.37 EUR per kilo of fish, see data section for further details. The EC scenarios are equal to the three FR scenarios except that the compensation is added to the price the fishermen receive. This results in three additional scenarios:

4. EC1_BAU for business as usual with compensation
5. EC2_National ITQ for the National ITQ system with compensation
6. EC3_Baltic ITQ for the Baltic ITQ system with compensation.

Environmental regulation (ER)

In the Environmental Regulation (ER) scenarios, fishermen are forced to maximise catches. This is not in line with maximising profitability since the economic profit maximisation (Maximum Economic Yield, MEY) most often does not occur where the long run sustainable catches are maximised (Maximum Sustainable Yield, MSY). When catches have a positive effect on nutrient reductions, MSY might be a better option for society than the MEY. Within the ER setting two scenarios are defined:

7. ER1_National ITQ for the National ITQ system maximising long run sustainable catches
8. ER2_Baltic ITQ for the Baltic ITQ system maximising long run sustainable catches.

These scenarios by definition reduces the profitability in the fishing sector compared to the other scenarios. Therefore, two additional scenarios are added where fisheries are compensated for not being allowed to fish at the profit maximising level. These scenarios are called:

9. ER3_National ITQ with compensation
10. ER4_Baltic ITQ with compensation.

Scenarios ER3 and ER4 are identical to ER1 and ER2 respectively, but money is transferred to the fishery so they get the same profitability as when fishing without the requirement to maximise catches.

Data

Danish fleet data is obtained from (i) the Danish Agrifish Agency, which comprises landings in weight and value and effort data at fishing trip level for the individual vessels, and (ii) Statistics Denmark's Account Statistics for Fisheries, which has provided the fleet cost data. Vessels are only included in the analysis (parametrisation of the model) if they appear in all three years 2012-2014, as the input data is based on an average over these three years.

Swedish landings and effort are extracted from logbooks. Price data is from the vessel's landing declarations containing total revenues and sold quantities. All data containing costs are obtained from the EU's economic data collection framework (Council Regulation (EC) No 1543/2000 of 29 June 2000). However, for the purpose of this analysis a specific group of pelagic vessels is extracted from the data.

Data on Finnish fisheries also stem from data collected under the EU economic data collection framework (Council Regulation (EC) No 1543/2000 of 29 June 2000). The central control register on the commercial fishery is the main source of data, which includes landings, the vessel register, first hand sales of quota species, the financial database in Statistics Finland (SF) and an additional account survey.

In total, the analysis contains 13 fleet segments. Data comprise 9 Danish, 2 Swedish, and 2 Finnish segments. All segments target herring and sprat in ICES areas 25-32 in the Baltic Sea. Table 1 shows the number of vessels and days at sea per vessel for each segment in areas 25-32 in 2015.

Table 1. Fleet segments catching herring and sprat in ICES areas 25-32

Fleet segment	DAS*/Ves** 2015	Ves** 2015	Description
<i>Denmark</i>			
Purse40m	6.4	4	Purse seiners > 40 meters
Sein1518m	19.5	7	Danish seine 15-18 meters
Tra1215mBA	106.3	27	Trawl 12-15 meters operating primarily in the Baltic Sea
Tra1518mBA	81.0	28	Trawl 15-18 meters operating primarily in the Baltic Sea
Tra1215mNS	3.3	5	Trawl 12-15 meters operating primarily in the North Sea, but with catches of sprat and herring in area 25-32
Tra1518mNS	13.8	12	Trawl 15-18 meters operating primarily in the North Sea, but with catches of sprat and herring in area 25-32
Tra2440mInd	13.2	3	Industrial trawl 24-40 meters
Tra2440mMix	2.3	6	Mixed trawl 24-40 meters
Tra40mInd	13.7	16	Industrial trawl >40 meters
<i>Sweden</i>			
PEL1824	71	9	Pelagic vessels 18-24 meters
PEL24XX	64.5	21	Pelagic vessels >24 meters
<i>Finland</i>			
TM1224	83	41	Pelagic trawlers 12-24 meters
TM2440	127	22	Pelagic trawlers 24-40 meters

Note: DAS*=Days at sea; Ves**=Number of vessels

Turning to the value of nutrient reductions, Hjerne and Hansson (2002) have estimated the nitrogen and phosphorus content of herring and sprat in the Baltic Sea. Their findings show a content of 2.4 per cent of nitrogen and 0.43 per cent of phosphorous. To calculate the value of a kilo of fish removed, data on how much society values reductions of both substances is needed. The approach taken for

this is based on the abatement costs using alternative sources of reduction, primarily land based. It is assumed that the cost of removing one kilo of nitrogen is equal to 3 EUR (30 SEK) and 67 EUR (652 SEK) per kilo of phosphorus based on table 1 in Gren et al. (2008). The estimate is based on a 20 per cent reduction level of the total load of nitrogen and phosphorus to the Baltic Sea. Using this and the nutrient content in the fish, this equals a total value of 0.37 EUR per kilo of landed fish.

3.1.2 Results

In this section we present the total reduction of nitrogen (N) and phosphorous (P) from the different policy scenarios. Total reductions in tonnes are presented in figure 1.

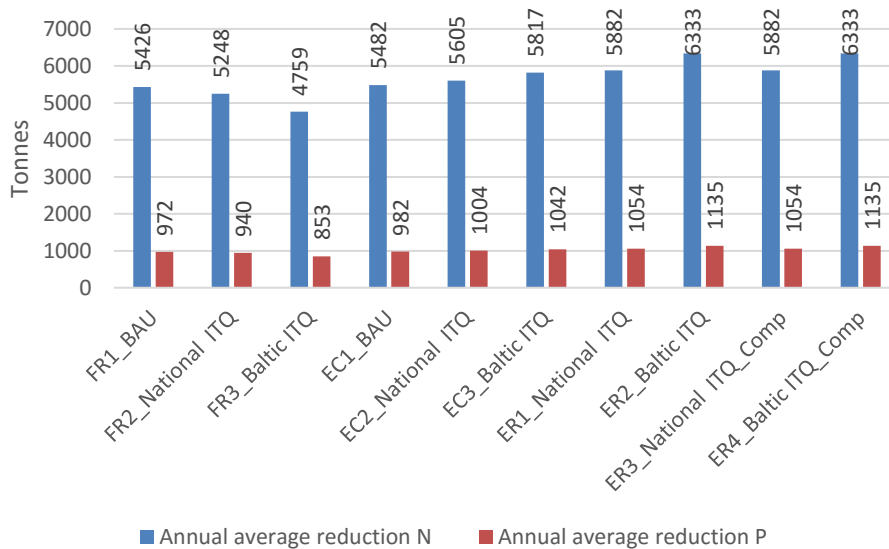


Figure 1. Total annual reduction of nitrogen (N) and phosphorous (P) in different scenarios (tonnes)

In the baseline scenario, FR1_BAU, fish landings correspond to a removal of 5,426 tonnes of nitrogen and 972 tonnes of phosphorous. To set the figures into perspective, the annual reduction target in HELCOM (2013) is 118,000 tonnes of nitrogen and 15,000 tonnes of phosphorous. Introducing ITQ systems that are more flexible will reduce the nutrient reduction. The reason for this is that these systems focus on maximising the private profits in the industry, which is done by reducing catch levels. In these scenarios, the fishing industry does not take the value of nutrient reduction into account when deciding catch levels. Turning to the EC scenarios, the nutrient reductions increase as expected. The fishing industry is compensated for the value of nutrient reduction and thus considers this when deciding catch levels. However, the largest reduction levels are in the ER scenarios, where catches are forced to be at the long run sustainable maximum. Since catches are maximised, so will nutrient reduction by definition. The topic of interest here is whether these reductions are worth more to society than the loss in economic profitability for the sector.

Figure 2 shows the compensation for nutrient reduction paid to fishermen per kilo of catch above current catches (BAU scenario) for the EC scenarios. The reason for calculating the value per additional catch is that the purpose of the subsidy is not to pay compensation for current catches but to increase the catch level above what the fishery is already catching today.

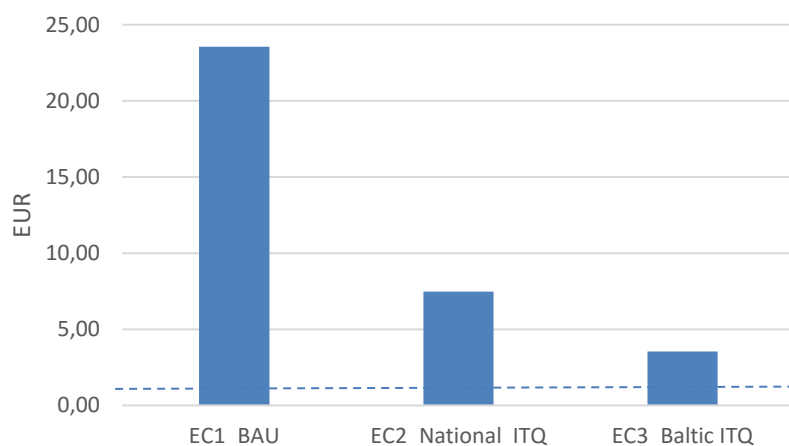


Figure 2. Compensation to fisheries, EUR per kilo of catch above current catches, Economic Compensation scenarios

It is obvious from the figure that the compensation paid to the fishing sector is above the value of nutrient reduction to the society of 0.37 EUR per kilo of fish (dotted line). The reason is that in these scenarios all fish are subsidised, i.e. also fish that was already caught with current fisheries management. Paying the full compensation for nutrient reduction will increase nutrient reduction (figure 1) but the cost in form of subsidies is too high compared to the additional nitrogen and phosphorous removed from the sea. The corresponding results for the ER scenarios are presented in figure 3 below.

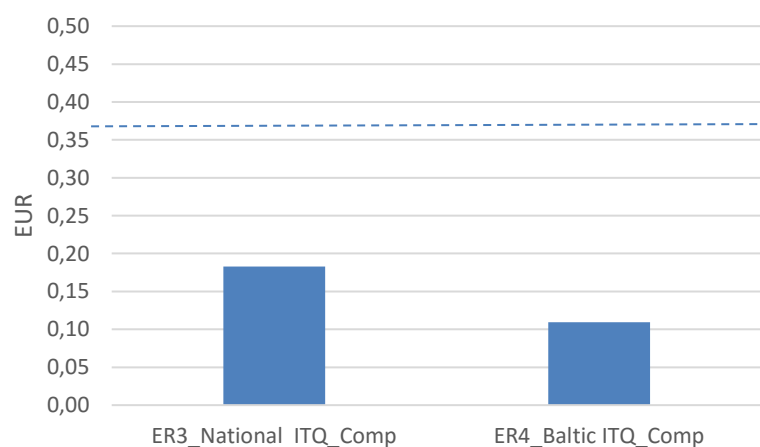


Figure 3. Compensation to fisheries, EUR per kilo of catch above current catches, Environmental Compensation scenarios

In the ER scenarios, the subsidies paid to the fishing sector for additional catches are below 0.37 EUR (dotted line). Thus, it would be profitable for society to force fisheries to maximise catches and then compensate the sector for the reduced economic profitability. The lowest subsidy would be when using a Baltic ITQ system, i.e. when the fishery is given maximum flexibility to trade quotas in order to improve catch efficiency. The total value of the fishery including both profits and the value of nutrient reduction is presented in figure 4 for each scenario.

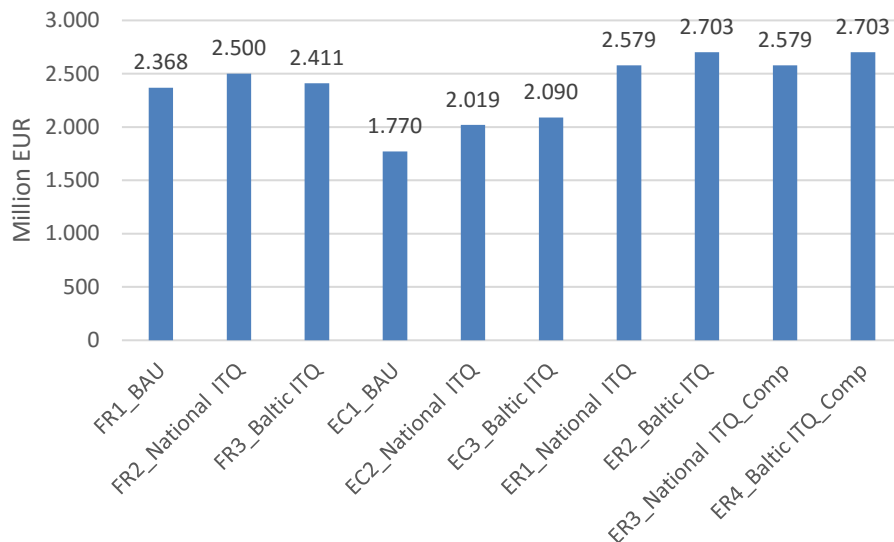


Figure 4. Net present value of profits and nutrient reduction over the 24-year period analysed

The highest total value is in the ER scenarios with high flexibility in quota trade. ER2 is without compensation and ER4 is with compensation included. The total value is the same in these scenarios, the difference being a pure reallocation of funds. An interesting result is that the economic value to society decreases in the fisheries regulation (FR) scenarios, when moving from a national to a Baltic ITQ system. The profitability in the sector actually increases, but catches decrease to such an extent that the overall effect is a decrease in total value to society.

The conclusion from the fisheries analysis is that maximising catches might be an efficient policy, because landed fish has a positive value to society in the form of marine nutrient reduction. Nutrient reduction in the Baltic Sea is an important goal in environmental policies ((WFD and MSF)) and fisheries contributes substantially to this target through the removal of nutrients. Fisheries policies aiming at the Maximum Sustainable Yield would from an eutrophication perspective be preferred to alternatives with higher stock biomass and less biomass removed from the ecosystem. In conclusion fisheries and fisheries management can help to reduce eutrophication and to reach the goal of a good environmental status in the Baltic Sea together with other land and sea based mitigation measures.

3.2 Case study 2: The joint environmental effect of fisheries and aquaculture

3.2.1 The use of Baltic Sea Fish Feed (BSFF)

What is the joint environmental effect on nitrogen and phosphorus levels in the Baltic Sea if fish from the Baltic Sea was used as feed for the aquaculture sea cage farming?

The first aim in this second case study is to study the joint environmental effect of fisheries and aquaculture if Baltic Sea Fish Feed (BSFF) was used. Fish meal is one of the most important ingredients in the fish feeds. Conventionally, ingredients for fish feed are bought by the feed producers on the global commodity market. Several criteria, especially price and availability, have been the most important factors affecting purchase decisions. Due to the eutrophication, the biggest environmental concern of Baltic Sea aquaculture has been nutrient release from sea cage farms.

The use of BSFF would open up a possibility to close the nutrient loop in the aquaculture industry. Fish raw material for the BSFF would be captured from the Baltic Sea. The mass balance of nutrients in the Baltic Sea would remain unchanged if BSFF was used, and the amount of nutrients in fish feed raw material would correspond to the nutrient emission from aquaculture. The positive externality from fishing would cancel out the negative externality from aquaculture, so the joint net effect would be zero.

The net nutrient load can be calculated with a simple mass balance calculation. Table 2 presents the parameters used in the mass balance calculation.

Table 2. Parameters used in nutrient mass balance calculation in Finnish marine salmon trout farming.

Parameter		Unit
Phosphorus load from fish farming	4.2	Kg/tonne edible production
Nitrogen load from fish farming	39.0	Kg/tonne edible production
Phosphorus in Baltic herring	4.3	Kg/tonne edible production
Nitrogen in Baltic herring	23.3	Kg/tonne edible production
Feed conversion rate (FCR)	1.15	Fish feed kg/kg fish
Fish meal in fish feed	17 or 29	% of fish feed
Fish meal from Baltic herring	20	% of kg Baltic herring

These parameter values are estimated based on the interviews with representatives of Finnish environmental authorities, fish meal and fish feed industry.

1 tonne of Baltic herring includes 4.3 kilos of phosphorus and in the Finnish aquaculture the released emission from 1 tonne of salmon trout produced is 4.2 kilos of phosphorus. The compensation conversion rate is $4.2/4.3 = 0.977$, i.e. 977 kilos of Baltic herrings should be fished in order to compensate phosphorus load by fishing. Nowadays, about 1.15 tonnes of feed is needed to breed 1 tonne of salmon trout ($FCR = 1.15$) in Finland. One receives 200 kilos of fish meal from 1 tonne of Baltic herring, and in the case that 17 per cent of the fish feed ingredients is fish meal, the phosphorus net load will be zero.

1 tonne of Baltic herring includes 23.3 kilos of nitrogen, and in the Finnish aquaculture the released emission from 1 tonne of salmon trout produced is 39 kilos of nitrogen (compensation rate being 1,673). If 17 per cent fish meal is used in fish feed, the nitrogen net load will be 42 per cent less than needed for nitrogen neutral aquaculture. The nitrogen net load will be zero, if the share of fish meal

is 29 per cent. However, in that case 71 per cent more phosphorus would be removed from the sea than needed for zero net loading. One middle course option could be that fish meal share is adjusted to 21.4 per cent. In that case the phosphorus net load would be 26 per cent higher (over compensation) and nitrogen net load 26 per cent lower (under compensation) than zero net loading, if this approach is accepted as a balanced nutrient neutral solution taking into account both phosphorus and nitrogen.

The sustainable growth of the aquaculture sector is one of the key objectives in the European Maritime and Fisheries Fund Operational Program for Finland 2014-2020 (European Commission 2014). BSFF has been identified as a potential concept to recirculate nutrients from aquaculture in the Baltic Sea, and several studies and administrative programs recommend the use of BSFF (Finnish Government 2014; Finnish Ministry of the Environment 2013; Mäkinen et al. 2013; Silvenius et al. 2012).

The Finnish multiannual strategic plan for Aquaculture aims at about 10,000 tonnes of production increase during the financing period 2014-2020 (Finnish Government 2014). In the following calculation we show how this growth could be realised with no net increase in the phosphorus loading. 11,500 tonnes BSFF is needed to produce 10,000 tonnes of salmon trout, if FCR is 1.15. 9,775 tonnes of Baltic herring is needed to produce 1,955 tonnes of fish meal, and subsequently 11,500 tonnes BSFF in the case fish feed includes 17 per cent fish meal. The other ingredients in the fish feed (9,500 tonnes) contains 40 tonnes of phosphorus. The same amount of phosphorus is removed from the system, because it is bound in the produced salmon trout. The phosphorus loading from aquaculture is 42 tonnes (10 000 tonnes * 0.42 per cent) and the phosphorus removal is the 42 tonnes (9,775 tonnes * 0.43 per cent), net phosphorus load being 42 tonnes – 42 tonnes = 0. The phosphorus flow is illustrated in figure 5.

What are the potential benefits of using Baltic Sea feed?

The use of BSFF creates economic benefits along the whole value chain. For the fishing industry, it means new markets and better use of Baltic herring quota. The Baltic herring stock in the Bothnian Sea has been in a very good condition and the quotas have been increasing up to 2017. Finland lost food fish market for Baltic herring market due to the Russian import ban in August 2014. In each of the years 2015-2017, about 40,000 tonnes of Finnish Baltic herring quotas were not utilised (Finnish Professional Fishermen's Association 2018).

BSFF creates a totally new industry concept in Finland, meaning that local fish meal and feed industries are closely integrated with local fishing, aquaculture and the fish processing sector. In addition to a better integrated production chain, it enables new marketing possibilities, which utilise consumers' demand for locally produced environmental-friendly products. Finnish consumers, fish wholesalers and processors have long suffered from shortage of domestic fish, which has led to increasing import of Norwegian salmon and Swedish salmon trout. Furthermore, Finnish export of salmon trout has been growing, which has even worsened the shortage of salmon trout in the domestic market. In 2016, the total market of salmonids was almost 50,000 tonnes. Domestic production of salmon trout was 13,400 tonnes and about 10,000 tonnes of salmon trout was imported from Sweden, as well as 25,000 tonnes of salmon from Norway. Swedish salmon trout was produced by Finnish fish farmers. They have expanded to Sweden, because it has been easier to receive sufficient environmental licenses from Sweden than from Finland. BSFF would create an opportunity for sustainable production growth on the Finnish coastline.

In this section we focus on analysing the direct economic benefits for the value chain, i.e. value added to the value chain, if the Finnish multiannual strategic plan for Aquaculture objective of 10,000 tonnes production is realised by applying the BSFF concept to the Finnish fish farming industry. Value added to the value chain describes how much additional economic value is accumulated in the different parts of the value chain, because BSFF enables new economic activity in production and trade.

The BSFF value chain begins with the fishing industry, which captures fish for local fish meal production (figure 5. BSSF fish value chain). The fish is sold to factories where fish meal and fish oil are manufactured and sold to local fish feed factories. Fish farmers buy fish feed from the feed factory and produce salmon trout to the processing industry, which in turn produces fillets and other products to catering and retail sectors for further delivery to consumers. In reality, the value chain is more complex – there are transporters, wholesalers and some other sectors involved in the value chain, but this simplified value chain works very well in order to describe the size of the economic opportunity linked with the BSFF.

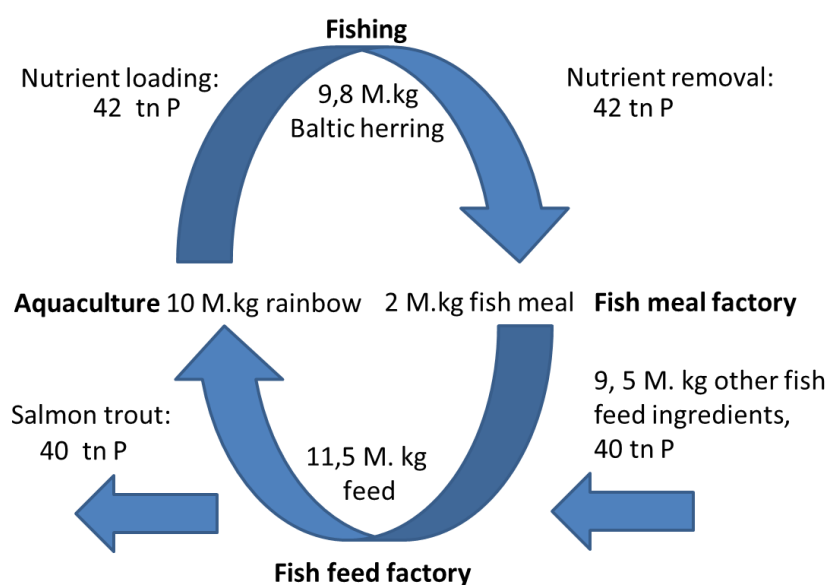


Figure 5. Fish and phosphorus flow in the BSFF production chain

The producer price of salmon trout varies in time according to the global salmon market, but if we use a long-term approximate of 4 EUR per kilo, the value of 10,000 tonnes of production is about 40 million EUR (table 3 and 4, figure 6). The value of this production is about 70 million EUR on the wholesale level and over 100 million EUR on the retail level.

Table 3. Parameter values used in economic calculations

Product	Price, EUR/kg			Fish meal from Baltic herring	Fillet from salmon trout
	Gutted	Fillet			
	Producer	Wholesale	Retail		
Baltic herring	0.2				
Fish meal	1.4			20 %	
Fish oil price	1.6			6 %	
Fish feed, 17 % fish meal	1.1				
Fish feed, 29 % fish meal	1.25				
Salmon trout	4.2	11.0	17.0		70 %

Fish prices are long-term rounded average of the producer prices and raw material for fish feed and fish feed prices are estimated in co-operation with Finnish fish feed industry.

Table 4. Production volumes, turnover and the value added in a phosphorus neutral BSFF value chain

BSFF value chain	Production volume	Turnover	Value added		
	Tonnes	1,000 EUR	% of turnover	1,000 EUR	%
Fishing	9 775	1 955	47	919	2
Fish meal and fish oil production	2 542	3 675	20	735	2
Fish feed production	11 500	12 650	20	2 530	5
Fish farming	10 000	40 000	31	12 400	26
Processing	7 000	56 000	16	8 960	19
Retailing	7 000	112 000	19	21 280	45
Total				46 824	100

Value added per cent for the different sectors are calculated as the average of years 2010-2014. The percentage for fish meal, fish oil and fish feed industry is estimated, because of the lack of data (Pokki et al. 2016).

Almost 10,000 tonnes of Baltic herring is needed to produce fish meal and fish oil for this production. The cumulated value added from the entire value chain from fishing to retail sector is nearly 47 million EUR. This net benefit to the Finnish economy can be achieved with the BSFF circular economy concept in a phosphorus neutral way. One third of the value added is realised in the primary and fish feed sectors and two thirds in the processing and trade sectors.

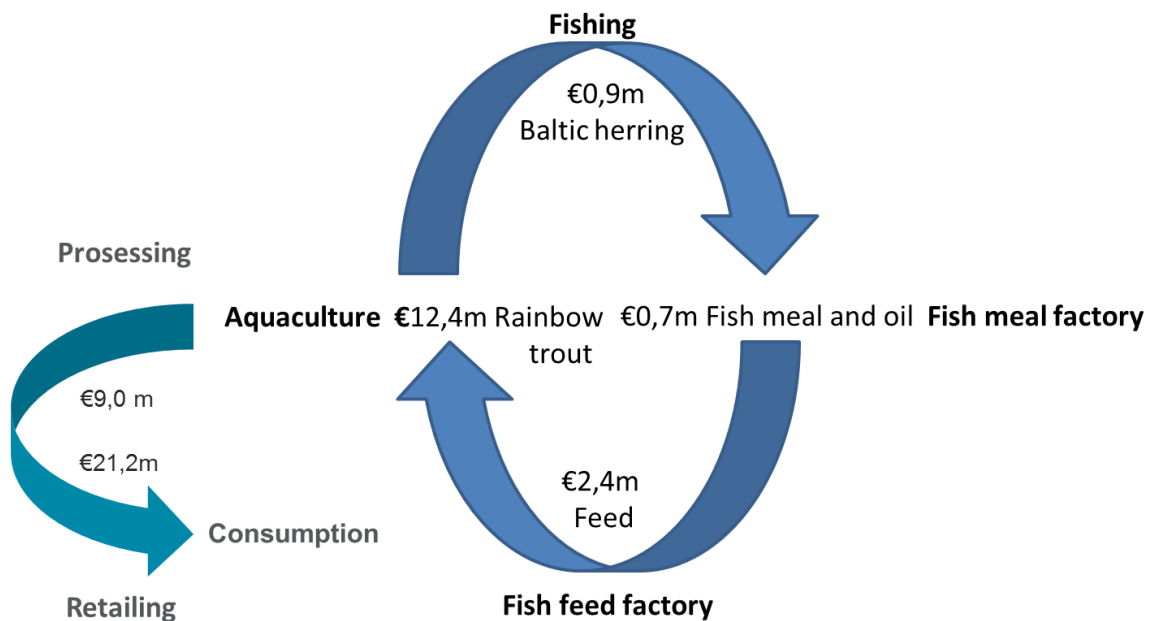


Figure 6. Value added in the BSFF value chain

In the preceding analysis, we calculated value added for the value chain based on the phosphorus balance. If nitrogen emission is totally compensated with BSFF, 6.7 tonnes more Baltic herring is needed for fish meal production, and 1.4 tonnes more fish meal is needed for fish feed production. This fish meal replaces other protein sources such as soy meal in fish feed. Therefore, the fish feed production volume remains the same, but the value of production increases as fish ingredients are more expensive than soy ingredients. This would mean higher costs and less profit for fish farmers, who want to grow their production with BSFF (table 5). Another option is that fish farmers receive higher price covering the cost increase and their profit will remain the same. This is possible, if consumers are willing to pay some premium for higher quality and more environmental-friendly end-products. This can be true, because increased nutrient removal high fish meal content in fish feed contributes to high omega-concentration and better taste of end-products. In the value added calculations (table 6), we assumed that prices on processing and retail level follow proportionally the price changes on producer level. A third alternative is that feed factories manufacture fish feed with the same fish meal content than in the phosphorus case (17 per cent fish meal) and fish meal factories sell the surplus production to other markets. This would guarantee that enough fish is caught to remove all needed nitrogen, but the price of fish feed remains the same as in the phosphorus case.

In monetary terms some 0.7 million EUR more added value is created to the fishing sector, 0.5 million EUR to the fish meal sector and 0.3 million for the fish feed sector. The value added for the fish meal sector is higher than for the fish feed sector, because more fish oil is produced than needed for BSFF production and fish meal factories can sell this surplus production to other markets. However, the value added for the fish farming sector will decrease by 1.6 million EUR in the case that the fish farming sector has to absorb this cost increase without any price compensation from the market (table 5). The value added for the whole value chain would be approximately at the same level as in the phosphorus balance calculation.

Table 5. Production volumes, turnover and the value added in the nitrogen neutral BSFF value chain. Increased feed costs decreases value added in the fish farming sector.

BSFF value chain	Volume	Turnover	Value added		
	Tonnes	1,000 EUR	% of turnover	1,000 EUR	%
Fishing	16,675	3,335	47	1,567	3
Fish meal and fish oil production	4,025	6,270	20	1,254	3
Fish feed production	11,500	14,375	20	2,875	6
Fish farming	10,000	40,000	27	10,800	23
Processing	7,000	56,000	16	8,960	19
Retailing	7,000	112,000	19	21,280	46
Total				46,736	100

In the case that consumers are willing to pay price premium, the overall value added along the value chain would be close to 50 million EUR, almost 4 million EUR more than in the preceding cases (table 6).

Table 6. Production volumes, turnover and the value added in the nitrogen neutral BSFF value chain. Consumers are willing to pay more.

BSFF value chain	Volume	Turnover	Value added		
	Tonnes	1,000 EUR	% of turnover	1,000 EUR	%
Fishing	16,675	3,335	47	1,567	3
Fish meal and fish oil production	4,025	6,270	20	1,254	3
Fish feed production	11,500	14,375	20	2,875	6
Fish farming	10,000	41,725	30	12,400	25
Processing	7,000	58,145	16	9,346	19
Retailing	7,000	116,830	19	22,198	45
Total				49,641	100

In the third option the value added for the fishing and fish meal sectors increases, but the other sectors remain the same as in the phosphorus case (table 7). The overall value added is about 49 million EUR.

Table 7. Production volumes, turnover and the value added in the nitrogen neutral BSFF value chain. 17 per cent fish meal is used.

BSFF value chain	Volume	Turnover	Value added		
	Tonnes	1,000 EUR	% of turnover	1,000 EUR	%
Fishing	16,675	3,335	47	1,567	3
Fish meal and fish oil production	4,025	6,270	20	1,254	3
Fish feed production	11,500	12,650	20	2,530	6
Fish farming	10,000	40,000	27	12,400	25
Processing	7,000	56,000	16	8,960	23
Retailing	7,000	112,000	19	21,280	41
Total				48,901	100

Summing up, we conclude that the concept of BSFF offers managers a new approach to consolidate blue growth and environment protection goals. BSFF opens up an opportunity to recirculate nutrients in the Baltic Sea. The Finnish multiannual strategic plan for Aquaculture targets at about 10,000 tonnes production increase. Fulfilment of this production growth with BSFF would create 46-50 million EUR value added to the fish value chain, and all this without any additional nutrient load to the Baltic Sea. In addition, use of BSFF would create new markets for Baltic herring and result in better utilisation of existing fish quotas.

3.2.2 IMTA systems

What are the costs and benefits of implementing local IMTA systems?

The idea behind an Integrated Multi-Trophic Aquaculture (IMTA) system is that different levels of trophic production can benefit from each other. Thus, the aim is to recycle released nutrients from one production in other kinds of production, which can obtain these nutrients. In this case, the surplus of nutrient from a fish farm can benefit other kinds of production at lower trophic levels, such as mussel and seaweed.

From an environmental perspective the effectiveness of an IMTA is measured on its ability to absorb and recycle the nutrients within the system, which potentially could have a negative effect on the surrounding environment. However, if such a system for parametrisation of the model should work efficiently from an economic perspective, the total outcome in terms of the value to society (including total production profit and positive/negative environmental externalities) generated from the production should be positive. Furthermore, if larger gains can be achieved when producing each type of product individually this should be preferred. Finally, if the contributions to society are negative they should not be produced.

In Europe, the main approach towards aquaculture production is a single species approach and the experience of using IMTA systems at a commercial scale are almost non-existing (Kleitou et al. 2018). This might be perceived as a contrast to the aim of using the sea as a more active part of the solution to fight eutrophication. However, using for example mussels as mitigating culture in combination with fish (IMTA) as suggested by Chopin et al. (2001) and Troell et al. (2009) is questionable, because mussels only capture nutrients in particulate form. This means that the mussels only to a limited extent will be able to obtain the nutrients discharges from the fish farm. Furthermore, mussels interring in an IMTA system with a fish farm will not be able to filtrate large parts of the nutrients released do to hydrological conditions around fish farms (Cranford et al. 2013). As such, IMTA farming systems where mussels mitigate the nutrient released from a fish farm should be evaluated from a mass balance principle. This is because it is not possible to remove exactly the same nitrogen and phosphorous molecules, which is released from the fish farm (Cranford et al. 2013).

Another issue concerning the use of IMTA is that the benefit of integrating the production of fish in open waters with production of mussels or seaweed seems limited. The positive nutrient effects only seem to appear very close to the fish farms (0-60 meters) (Kerrigan & Suckling 2018). However, the close proximity to the fish farm can create problems for the fish because it hinders a free flow of water, and it may also hinder an effective management of the fish farm due to limited access to the farms. Furthermore, the optimal location for a fish farm may not be the optimal location for either mussel or seaweed production. Thus, from an environmental perspective, the nutrients released from one source of production should just equal the nutrients removed from another mitigating activity, if local

concentration is not an issue. If local concentration is an issue, such as organic waste under a fish farm, this could be handled using fallow periods in an open sea environment. The effect of local concentration of nutrient such as nitrogen and phosphorus seems less important in an open sea environment (Kerrigan & Suckling 2018).

In light of this basic understanding of mussel (and seaweed) mitigation cultures, and from an environmental and economic point of view, the mussel and seaweed farms should be placed where the highest environmental effects can be realised at the lowest cost possible. Thus, the issue of how close or how far the mitigating measures are placed from a fish farm or other point source polluter does not matter (Petersen et al. 2016).

All in all, the cost and benefits of using mussels and seaweed as mitigating measures should be carefully studied and these measures should only be implemented if the net costs of using these abatement measures are lower or benefits higher than that of other alternatives, otherwise they will represent a loss to society. In terms of using IMTA systems, there is at the moment no clear evidence that IMTA systems will provide a larger benefit to society than using a single species approach.

Mussels and seaweed as a compensation tool in the Baltic Sea

To evaluate the economic possibilities of using mussels and seaweed in an IMTA setting, it is important to know the contribution (nutrient extraction) and cost of these measures. This information is important to be able to compare the environmental economic efficiency of these mitigation measures with other measures extracting or reducing the nutrient load in the marine environment. At the same time it will provide the needed information to be able to evaluate whether IMTA systems consisting of fish farms and mussels or seaweed compensation would be a benefit to society.

Around the Baltic area, only a few applied studies have identified the benefit and cost of removing nutrient from the estuarine environment in larger scale using mussels (Lindahl 2011; Petersen et al. 2014) and from a more theoretical perspective (Gren et al. 2009). These studies are all using a single species approach. The studies on cultivation of mussels have been carried out in Denmark and on the west coast of Sweden (Lindahl et al. 2005; Plesner et al. 2015; Timmermann 2014). The studies on mussels have been showing promising results in terms of removing nitrogen and phosphorus. However, the production of seaweed seems more challenging (Bruhn et al. 2016) and is currently not considered an effective tool to remove nitrogen and phosphorus in a cost efficient manner (Timmermann 2014).

When focusing on the Baltic Sea, one of the major challenges of producing both mussels and seaweed is the salinity level. The salinity level in the Baltic Sea is low compared to the North Sea and this reduces the growth potential for both mussels and seaweed. The slower growth increases the production cost and thereby the cost of removing nutrients. It also makes it difficult to produce mussels of sellable sizes for human consumption (Gren et al. 2009). Today, neither mussels nor seaweed producers are able to obtain a net profit from production when not harvested for human consumption. This also implies that the use of these compensating tools represents a cost for the private producer. Thus, these measures will only be applied if these compensation tools become relatively less expensive to use compared to other abatement alternatives used today or enforced by legislation.

Presently, experimental studies are carried out in the Nordic countries to find out more about alternative uses of these products, such as feed for fish and terrestrial animals (Nørgaard et al. 2015), fertiliser, biogas, etc. (Plesner et al. 2015). At the moment, the knowledge about the cost of using

seaweed and mussels for these alternatives is very limited, but it seems to be too high to offer an economically attractive solution (Plesner et al. 2015; Timmermann 2014).

In Denmark, fish farms can be established in the coastal areas (1 nautical mile from the coast) if nutrients (nitrogen and phosphorus) are removed 1:1 using mussels or seaweed according to Danish legislation concerning the estuarine water environment. Now, new fish farms can also be established outside the coastal areas with a total nitrogen emission of 800 tonnes. However, if they affect coastal areas where the environmental reduction target has not yet been reached they should compensate for this emission within that catchment area. The Danish regulation is based on the IMTA idea; however, the environmental benefits and economic costs of using this approach have not been evaluated before introducing the regulation, using these particular abatement measures. In order to have a common reference when analysing the environmental effect of a sea cage farm a new concept for a standard sea cage farm has been developed in Denmark. The environmental impact is 100 tonnes of nitrogen and 12 tonnes of phosphorus, with a production of 2900 tonnes of fish (trout).

To extend the knowledge about mussels as a compensation tool, two larger scale experiments have been carried out in Denmark. These studies should reveal how much nutrient can actually be removed and at what cost. The area used for the production has shown to be site specific and will be dependent on the technology used and the efficiency and production achieved within each specific area.

Mussels (Skive Fjord)

A full scale facility was located in Skive Fjord in 2010-2011. The potential removal of nitrogen was measured to be 10-16 tonnes, which equals a harvest of 0.6-0.9 tonnes of nitrogen per hectare per year. The removal of phosphorus was estimated to be 0.03-0.05 tonnes of phosphorus per hectare per year. It should be mentioned that Skive Fjord is highly eutrophic (Petersen et al. 2014; Timmermann et al. 2014). Furthermore, the realised removal of nitrogen and phosphorus is dependent on the harvest time, the yield and the content of nitrogen and phosphorus in the mussels at the time of harvesting (Timmermann et al. 2014).

The cost of production of mussels and removal of nitrogen in Skive Fjord was estimated to be between 70 and 97 DKK per kilo of nitrogen when harvesting between 0.6 and 0.9 tonnes per hectare (Timmermann et al. 2014).

Mussels (Horsens Fjord)

The facility placed in Horsens Fjord in 2011 and 2012 showed a greater potential removing 1.2-1.8 tonnes of nitrogen per hectare per year using a *SmartFarm* facility (Plesner et al. 2015). However, this farm was only running at 5-10 per cent of the maximal production capacity. The removal of phosphorus was estimated to 0.09-0.13 tonnes of phosphorus per hectare per year (Plesner et al. 2015).

The cost of production of mussels and removal of nitrogen in Horsens Fjord was estimated to be between 50 and 75 DKK per kilo of nitrogen when harvesting between 1.2 and 1.8 tonnes per hectare (Timmermann et al. 2014).

Seaweed

In comparison, the cost of removing one kilo of nitrogen using seaweed as mitigation is estimated to be between 2,106 DKK per kilo of nitrogen in Limfjorden and 5,825 DKK per kilo nitrogen in Horsens Fjord (Bruhn et al. 2014).

The conclusion to be drawn from the above is that IMTA systems combining fish farming with mussels or seaweeds have limited local effect on the environment in terms of extracting the exact same amount of nutrients that are released from aquaculture. Furthermore, the local concentration issues of nitrogen and phosphorus seem limited in an open sea environment. Thus, to have the highest possible effect of these mitigating tools they should be placed where the highest environmental effects can be realised at the lowest cost. Integrating these systems (IMTA) in an open sea environment will most probably not accomplish the goal of reaching good environmental status in a cost efficient manner.

Jacobsen (2017) estimated the shadow price of fulfilling the Danish goal of nitrogen reduction towards 2021 using land based measures. The shadow price per kilo of nitrogen was 63 DKK. Based on this, it can be concluded that using the existing knowledge and technology it still seems rather costly and uncertain to use mussels or seaweed as mitigating measures in the Baltic Sea, compared to existing land based alternatives for removal of nutrients (Eriksen et al. 2014; Gren et al. 2009; Petersen et al. 2014; Timmermann et al. 2014). However, new market for small mussels or knowledge and technology reducing the production cost of especially mussels could make this mitigating tool an interesting substitute for land based alternatives in the future, whereas the production of seaweed does not show the same potential. The introduction of such new tools also depends on how these are promoted through the regulatory setting in each country, and on how they could play a more integrated and active role in marine policy. Regarding this issue, some suggestions have already been put forward pointing towards developing transferable quota systems on nitrogen between sectors such as agriculture and aquaculture (Frost et al. 2014; Jacobsen et al. 2016; Lindahl et al. 2005; Lindahl & Kollberg 2008).

4. Summary/Concluding remarks

In this study, the economic importance of environmental externalities is analysed in two case studies. In the first case we focused on nutrient removal as a positive externality from fisheries, and evaluate which of three management policies will give the highest possible welfare benefits to society. The second case looks at the circulation of nutrients in an aquaculture farm setting using a mass balance perspective. Here nutrients are added as fish feed and removed again using fisheries. Furthermore, the potential of using an Integrated Multi-Trophic Aquaculture (IMTA) system to reduce local impact is discussed.

Focus in the fisheries case is on the fishing sector's removal of nutrients (N and P) from the Baltic Sea through the removal of fish biomass. A reduction of N and P is an important environmental policy objective in the region, and thus the fishing sector contributes to this objective. The value of this is analysed in different scenarios reflecting different management options aiming at improving the total economic contribution from fisheries. The idea is that if catches have a value to society in addition to the market value of the fish, there might be a case for increasing total catches beyond what is economically optimal for the private fishing firms. The scenarios are analysed using the FISHRENT bio-economic model for the pelagic fleets from Denmark, Finland and Sweden. The results show that giving the fishing sector full compensation for all nutrients removed from the Baltic Sea is an expensive way of increasing nutrient reduction. This is because the fishery already today removes nutrients through their fishing activities without any compensation. An alternative would be to regulate the sector to catch at the maximum sustainable catches (i.e. MSY), since this will remove more nutrients than fishing at the economically optimal catch level (i.e. MEY). Doing this will increase the overall value to society. Further, the analysis shows that policies regulating catch levels could be combined with more efficient systems for individual quotas (ITQs), such as allowing trade between countries, if managers want to further reduce the costs for nutrient removal. In conclusion, fisheries and fisheries management can help to reduce eutrophication and to reach the goal of good environmental status in the Baltic Sea together with other land and sea based mitigation measures.

The second case focused on the joint environmental effect of aquaculture fish production in the Baltic Sea, taking into account the effect of using fish feed based on Baltic caught fish (BSFF). Furthermore, the removal of nutrients was also considered through Integrated Multi-Trophic Aquaculture (IMTA) production systems breeding mussels or growing seaweed to reduce local impact.

Eutrophication is one of the main concerns for the Baltic Sea and therefore actions reducing or preventing nutrient loading to Baltic Sea are highly emphasised in the environmental policy. At the same time EU is concerned about growing dependency on fish import and wants to encourage fish production within the EU. Blue Growth including sustainable growth of the aquaculture sector is one of the key objectives in the EU and national policy. Baltic Sea Fish Feed (BSFF) has been identified as a potential concept to recirculate nutrients from aquaculture in the Baltic Sea, and several studies and administrative programs recommend the use of BSFF. The concept of BSFF offers managers a new approach to consolidate blue growth and environment protection goals. BSFF opens up an opportunity to close the nutrient loop in the aquaculture industry and create new value added for the society. The Finnish multiannual strategic plan for Aquaculture targets at about 10,000 tonnes production increase. According to this study fulfilment of this production growth with the BSFF concept would create 46-50 million EUR value added to the fish value chain without additional nutrient load to Baltic

Sea. Use of BSFF would create new market for Baltic herring and result in better utilisation of existing fish quotas.

The experience with IMTA systems in Europe is rather limited. However, based on the literature on mussel and seaweed production, IMTA systems combining fish farming with mussels or seaweeds seem to have limited local effect in terms of extracting the same amount of nutrients as released from the fish farm. Furthermore, the local concentration issues of nitrogen and phosphorus seems limited in an open sea environment. Thus, to have the highest possible effect of these mitigating tools they should be placed where the highest environmental effects can be realised at the lowest cost, and not necessarily in close proximity to the fish farm.

The estimated prices for removing one kilo of nitrogen in Denmark using mussels range from 50 to 97 DKK, which is in the range of other land based mitigation tools where the average shadow price has been estimated to 63 DKK, fulfilling the Danish goal of nitrogen reduction towards 2021. One major issue for both mussels and seaweed used for compensation is that there is no market for the products in larger scale and, therefore, they only represent a cost to the producer. New markets for small mussels or knowledge and technology reducing cost of production could make this mitigating tool an interesting substitute in the near future for land based alternatives, whereas the production of seaweed does not show the same potential, using current technology and operating within the existing market. However, integrating these systems (IMTA) with fish farming in an open sea environment will most likely not accomplish the goal of removing nutrients in the most cost effective manner.

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